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THE NIAGARA CUESTA FROM A NEW VIEWPOINT

By A. W. GRABAU

The generally accepted explanation of the origin of the Niagara Escarpment, or Cuesta, and that of the other cuestas which parallel it and which form such significant features in the physiographic history of the eastern United States, is by now familiar to all students of earth forms and their genesis. Outlined originally, in its fundamental features, by William Morris Davis, it has always formed one of the most satisfying examples of land forms produced by the activities of the agents of erosion in a region of simple structure and normal alternation of resistant and weak strata. This conception of the origin of these escarpments has thrown a flood of light upon the early history of the valleys now occupied by the Great Lakes and has furnished a key to the rational analysis of the rather complicated arrangement of many of our old and partially abandoned stream valleys, not only in New York state but also in the adjoining districts. As in the case of all great generalizations, however, prolonged study and discussion of the problems involved has led to amplification and, to a certain extent, modification of the original conception, and in this Davis himself has taken a leading part. As one who for more than two decades has been actively interested in the physiographic history of eastern North America and especially of the Great Lakes district, I am now impelled to summarize some of the results of my studies which involve a further modification of the interpretation of these escarpments and of the valleys paralleling and transecting them. If this shall result in removing these land forms from the category of the simple belted structure of an ancient coastal plain and make them the type of a geographic structure not heretofore so generally recognized, it can but serve the progress of knowledge.

THE TWO OLDER CONCEPTIONS OF THE ORIGIN OF THE CUESTA AND LOWLAND TOPOGRAPHY OF WESTERN NEW YORK

The original conception of the history of the strata which form the series of east-and-west ridges and lowlands so well displayed in New York state south of Lake Ontario can be gleaned from a perusal of our older textbooks of geology.¹ These strata were held to have been deposited in a sea progressively retreating southward, and the present northern edge of each formation was held to coincide approximately with the northern shore line of the sea in which each was deposited. Davis taught us to realize that the present limits of these strata were primarily produced by prolonged erosion

¹ See, for example, Joseph Le Conte's "Elements of Geology," 4th edit., New York, 1896, p. 309.

and that most, if not all, of the formations involved formerly extended much farther to the north—indeed, that they probably overlapped one another so that the northern portion of each came in turn to rest upon the crystalline rocks which formed the Canadian Oldland, against which these formations were deposited as coastal plain strata in the Paleozoic sea. The two contrasting conceptions just outlined are illustrated in the following diagrams, the first of which indicates the deposits formed in a retreating, the second in an advancing sea, the successive sea levels being indicated in numerical order (Figs. 1 and 2).

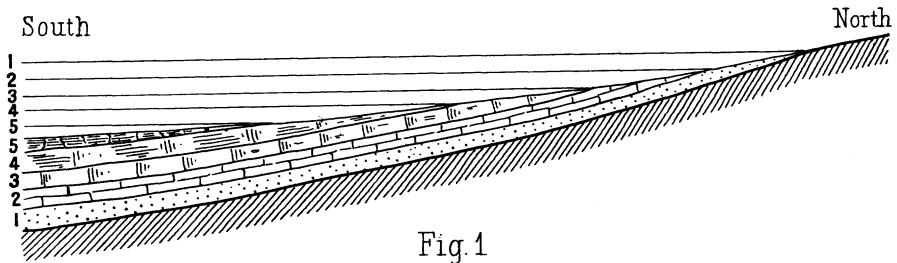


Fig. 1

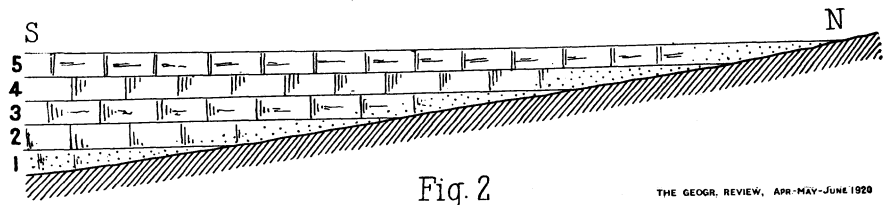


Fig. 2

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FIG. 1—Diagram showing the older conception of the order of deposition of the Paleozoic formations in eastern North America. The seashore is regarded as progressively retreating, each later formation being deposited over a smaller area than the preceding. Order of deposition: 1 to 5.

FIG. 2—A newer conception of the mode of deposition of the formations, each younger one overlapping the preceding.

The second interpretation does not necessarily imply such regularity of advance as is suggested by the diagram, for this is intended primarily to illustrate the general conception of a coastal plain series formed in a sea which on the whole was advancing over the oldland, and takes no account of minor irregularities of advance or of intermediate periods of partial retreat, followed by readvance.

From such a relatively simple coastal plain series, fringing an oldland which in part at least supplied the material of the coastal plain deposits, the peculiar cuesta and lowland topography so characteristic of this region was carved upon elevation, by the development of a normal sequential drainage system. The streams of the oldland became extended across the coastal plain and formed the original consequent rivers which began to cut down through the strata approximately at right angles to the original shore lines. The development of subsequent streams, more or less at right angles

to the consequents, began to strip away the portion of the coastal plain which rested against the oldland and so formed the first inner lowland belt. If the surface layer was a stratum of hard rock overlying one of softer material, a cliff was formed which faced this lowland and was separated by it from the oldland on the north. This cliff constituted the "inface" of the first cuesta, which was made up of the remnant of the coastal plain, left after the formation of the first inner lowland (Fig. 3). As the inface of the cuesta retreated under the influence of continued erosion the inner lowland was widened, and as the consequent streams continued to deepen their valleys the subsequent streams were likewise enabled to deepen the inner lowland. If a second hard stratum was discovered beneath the soft one on which the inner lowland was carved, a new cliff or inface came into

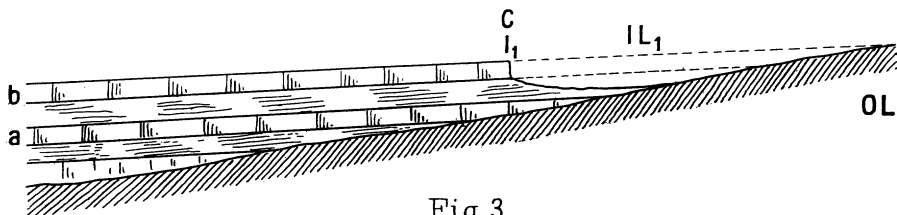


Fig. 3

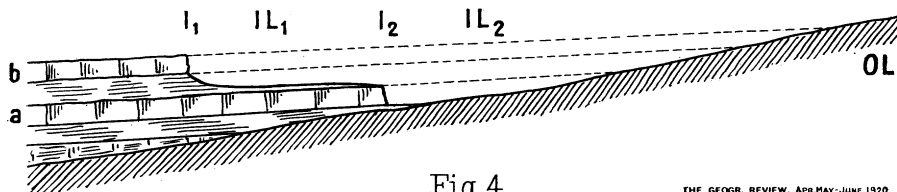


Fig. 4

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FIG. 3—Diagram showing early stage of dissection of the coastal plain, with the formation of an inner lowland (IL_1) which separates the inface (I_1) of the first cuesta (C) from the oldland (OL). a, b =hard strata.

FIG. 4—A later stage of dissection of the same coastal plain series. The second hard stratum (a) has been uncovered by the downward cutting of the streams, and a new inface (I_2) has been formed on it, with a new inner lowland (IL_2) between it and the oldland (OL). The first cuesta has been reduced by the seaward pushing, through continued erosion of the inface, and the migration of the first inner lowland (IL_1) in the same direction. As here shown, the two lowlands and cuestas are better regarded as a single terraced cuesta, comparable to the Niagara Cuesta, the lower part of which, seven miles north of the upper, is submerged by the waters of Lake Ontario. If the upper inface (I_1) were pushed by erosion far enough away from the oldland, the outer lowland (IL_1) would come to lie at the level of the inner one (IL_2) because of the dip of the strata.

existence as this second stratum was cut through to another softer one beneath it. Thus a double or twofold cuesta was formed, with two inner lowlands parallel to each other. These two stages are illustrated in the accompanying diagrams (Figs. 3 and 4).

A MODIFICATION OF THE ORIGINAL CONCEPTION

Another modification of this conception, which was held for a time, was in reality a combination of the two explanations of origin primarily given.

This was as follows: After the deposition of the first pair of soft and hard strata, the sea retreated, uncovering a part of the coastal plain, and upon this exposed portion was cut the first lowland faced by the escarpment or inface of the first cuesta. Meanwhile a second series of strata was forming in the still submerged portion of the coast, in part from the material eroded in the making of the first lowland and consequent valleys. When this second coastal plain series emerged, the process was repeated and the second lowland was cut, the second cuesta thus coming into existence. The adjoin-

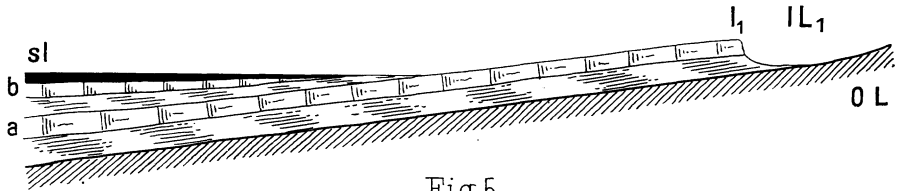


Fig 5

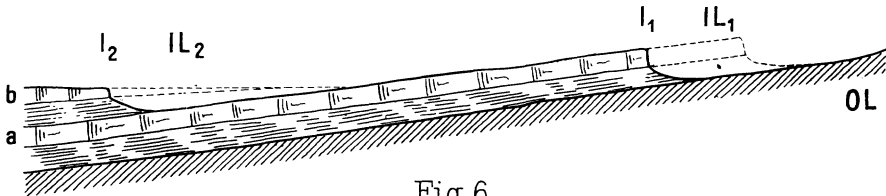


Fig 6

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FIG. 5—Diagram illustrating the conception of the cutting of a cuesta topography and inner lowland on the first set of strata and the simultaneous deposition of a second set of coastal plain strata in the sea. The sea is represented by solid black. a, b=hard strata; I₁=first inface; IL₁=first inner lowland; OL=oldland; sl=sea level.

FIG. 6—A later stage of the series illustrated in Fig. 5. The second coastal plain series has emerged, and a new inface has been cut on the upper stratum b, while the inface of the lower stratum has been worn farther back.

a, b, I₁, and IL₁ as in Fig. 5. I₂=second inface; IL₂=second inner lowland.

ing diagrams (Figs. 5 and 6) illustrate this conception of the course of events. It will be seen that the first inface is cut on the lower stratum (a) and the second on the higher one (b), whereas in the conception illustrated in Figures 3 and 4 the reverse is the case.

THE CUESTAS OF THE EASTERN GREAT LAKES REGION

So far, we have outlined the general theories of the development of coastal plain topography which were applied practically without modification to the ancient coastal plain of New York and adjoining regions as well as to the ancient coastal plain of central England and other districts. A number of cuestas and lowlands have been recognized in the New York region, the first cuesta of any significance, the northern, being that formed on the Ordovician limestones in Canada north of Lake Ontario. The second pronounced cuesta was formed by the Silurian limestones and constitutes

the well-known Niagara Escarpment south of Lake Ontario, this lake occupying the overdeepened second inner lowland. The third cuesta was formed by the Middle Devonian (Onondaga) limestone of western New York, which faces the Salina, or Tonawanda Valley, lowland, one of the prominent east-and-west valleys or lowlands of New York state. Still farther south lies

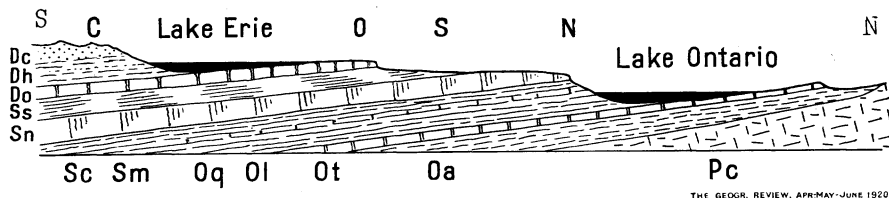


FIG. 7—Diagram illustrating the several cuestas and lowlands of western New York and Ontario and the strata from which they were cut.

N=Niagara Cuesta; S=Salina Lowland; O=Onondaga Cuesta; C=Chemung Cuesta. Pc=Pre-Cambrian; Oa=Lower Ordovician shales and limestones; Ot=Trenton limestone; Ol=Lorraine shale, etc.; Oq=Queenston red shale; Sm=Medina shales and sandstones; Sc=Clinton formation; Sn=Niagaran formation (Rochester shale and Lockport limestone); Ss=Salina shales; Do=Onondaga limestone; Dh=Hamilton shales, etc.; Dc=Chemung shales and sandstones. Preceding a small letter, O indicates Ordovician; S, Silurian; D, Devonian.

the fourth cuesta inface formed by the Upper Devonian (Portage and Chemung) sandstones, between which and the Onondaga Cuesta lies the lowland carved on the soft Middle Devonian (Marcellus and Hamilton) shales, the western part of this lowland being occupied by the eastern end of Lake Erie (Fig. 7). Owing to tilting after their formation the southern cuesta

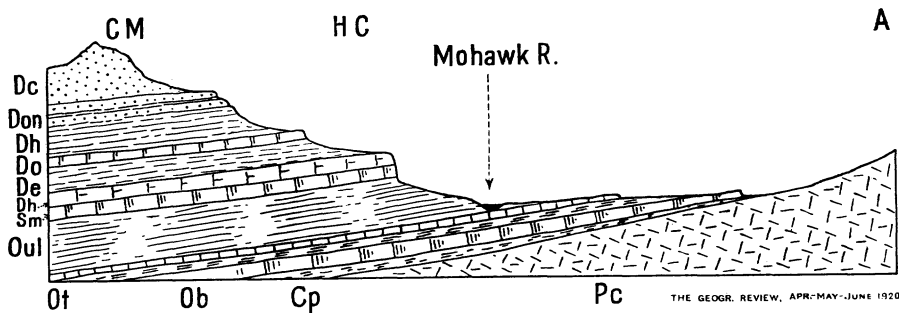


FIG. 8—Diagram illustrating the relation of the various strata to the single inner lowland (Mohawk Valley) and the terraced cuesta of the Helderbergs in eastern New York.

A=Adirondacks; HC=Helderberg Cuesta (terraced); CM=Catskill Mountains (monadnock). Pc=Pre-Cambrian crystallines; Cp, Potsdam sandstone; Ot-Ob=Ordovician limestone; Oul=Ordovician shales; Sm=Manlius limestone (Silurian); Dh=Helderberg limestone (Devonian); De=Esopus shale (Devonian); Do=Onondaga limestone; Dh-Don=Devonian shales and sandstones; Dc=Catskill sandstone.

is now much higher than those farther north. Eastward the Upper and Middle Devonian cuestas unite by the change of the Middle Devonian soft beds to harder strata, and so is formed the Helderberg Escarpment south of Altamont, which is further increased in height by the appearance of the

Lower Devonian (Helderberg) limestones beneath the Onondaga. The Salina and Niagara strata die out, and with them disappear the respective lowland and cuesta. The Lake Ontario lowland is continued in the

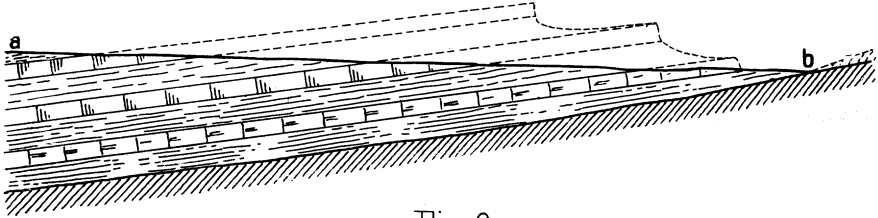


Fig 9

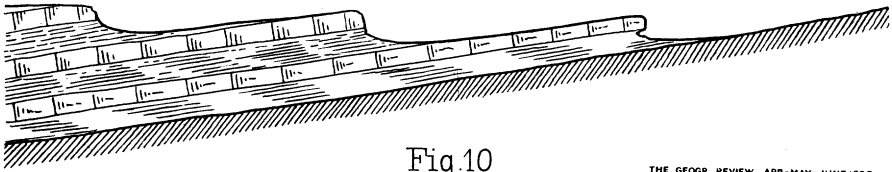


Fig. 10

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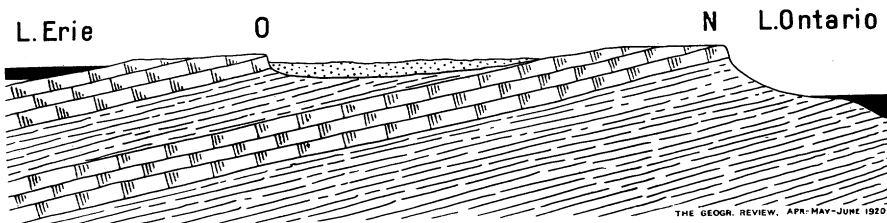
Fig. 9—Diagram illustrating beveling of the old Paleozoic coastal plain strata along the line ab by peneplanation in Mesozoic time.

Fig. 10—Diagram illustrating the formation of cuestas and lowlands on the hard and soft strata respectively by the Tertiary erosion.

Mohawk Valley, which thus lies at the foot of the combined Devonian cuestas on which the lower hard members form terraces. Thus in eastern New York there is only one lowland and one cuesta, which, however, is terraced. This is illustrated in Figure 8.

LATER MODIFICATION IN INTERPRETATION OF PHYSIOGRAPHIC HISTORY OF REGION BROUGHT ABOUT BY RECOGNITION OF PENEPLANATION

We come now to the later modification in the interpretation of the his-



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FIG. 11—Diagram showing the thinning of the hard beds on the Niagara (N) and Onondaga (O) cuesta edges, due to beveling of the hard strata during the peneplanation of the region.

tory of these topographic features and the change of opinion which came about by the recognition of the peneplanation of the region before the

development of the present river valleys and lowlands. Instead of considering that the region illustrates a succession of coastal plains on which the belted topography was developed or a succession of cuestas and lowlands developed as the result of the progressive uncovering of successively lower hard members in a single coastal plain, we now recognize that the present topography does not represent the first cycle of erosion but the last of an unknown number of cycles. We now recognize that all these strata were beveled across by the development of the Cretaceous peneplain, and that the successive lowlands were carved on the softer strata by the rivers of Tertiary time. This is illustrated in diagrammatic form in Figures 9 and 10.

This explanation involves only a minimum amount of retreat of the escarpments or infaces of the cuestas, which are on the whole very near the northern edge of the outcrops of the strata at the time of the completion of the peneplain. This is shown by the facts that only the lower parts of

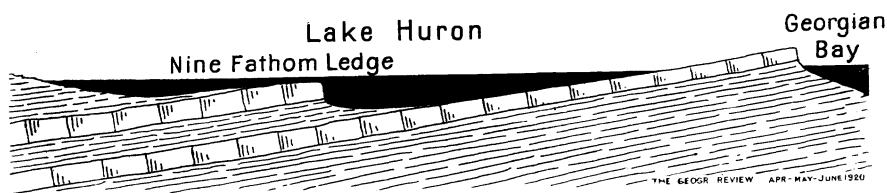


FIG. 12—Section through Lake Huron, from Saginaw, Mich., to Georgian Bay, showing the submerged (Onondaga) escarpment at Nine Fathom Ledge and the prominent Niagara Escarpment which faces Georgian Bay.

the hard formations are involved in the cliffs or infaces of the cuestas, the hard beds themselves having been beveled across. Thus in the Niagara Escarpment only the lower 25 feet of the Niagaran (Lockport) limestone is shown, the total thickness of which south of the falls is nearly 200 feet. At North Buffalo, where the Onondaga Escarpment is partly obscured by drift, only 30 or 40 feet of this formation remains, this being the lower part of the limestone which south of Buffalo retains its full thickness of over 150 feet. These features are graphically shown in Figure 11.

Though of little topographic significance at Buffalo, on account of obscuration by glacial drift, the Onondaga Escarpment becomes a prominent feature where it crosses diagonally through Lake Huron from north of Goderich, Ont., to Mackinac (for locations see map, Fig. 17), having a height of over 400 feet, although it is entirely submerged by the lake waters, as shown in the diagrammatic section (Fig. 12).

THE WRITER'S SUGGESTED MODIFICATIONS OF PRESENT VIEWPOINT

Thus far I have presented the views of the origin and relations of these

cuestas and lowlands generally held with more or less modification at the present time, and I now wish to present the modifications which further study of the problem seems to me to demand.

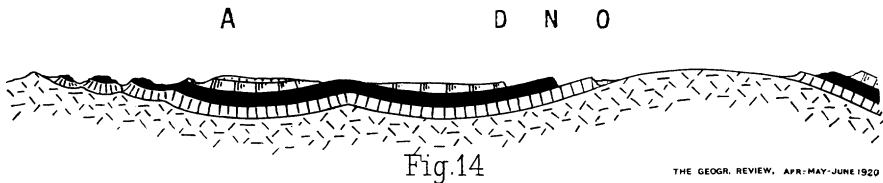
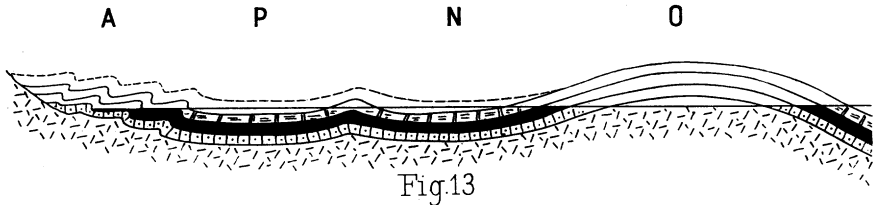
DERIVATION OF ANCIENT COASTAL PLAIN MATERIAL FROM APPALACHIA
AND NOT FROM THE CANADIAN OLDLAND

In the first place, our conception of the formations involved, as representing coastal plain strata deposited against and over the Canadian Oldland, requires to be revised. By definition the strata of a coastal plain are deposited upon and against an older, partly submerged land mass, the emerged part of which constitutes the "oldland" at the time of the deposition of the coastal plain strata beneath the sea or at its margin. Subsequent elevation brings a part of the coastal plain strata above the level of the sea, and this constitutes the coastal plain.

A critical examination of the Paleozoic strata of eastern North America leads to the conclusion that the oldland from which the fragmental material of these strata was derived was not the Canadian mass but a now vanished continent (Appalachia) which lay in the region of, and to the east of, the present Atlantic coast, a fact long known to geologists and physiographers. The strata involved in the folds of the Appalachian Mountains represent the nearshore ends of the formations which are now exposed in the edges of the escarpments in the belted country of New York, Michigan, and Wisconsin. The Canadian region lay a thousand miles or more from this shore, and there is now abundant evidence to show that, during a part of the time at least, it was completely submerged, forming a distant though comparatively shallow sea bottom. That the Ordovician, Silurian, and part of the Devonian beds extended entirely across the present crystalline surface of Ontario not only is shown by the presence of remnants of some of these strata upon this surface (as at Lake Temiscaming) and by the presence of most of them in the region to the north of the crystalline area in James Bay but also is a necessary inference demanded by the character of the strata and their faunas. I believe it is a sound conclusion generally held by paleogeographers that such formations as the Niagaran, for example, extended entirely across Ontario from the present Niagara Escarpment to the James Bay region and beyond to the Arctic. Here was for the most part a broad though shallow sea in Silurian time in which the coral reefs of that period were building, and, though here and there may have been islands of older rock and even peninsular extension of some land masses, yet on the whole this was a region of open sea, for here the limestones had their maximum thickness and their greatest purity. The fragmental beds which are still recognizable in New York as shales and sandstones have mostly thinned away in this more distant region by merging into the limestones.

THE ONTARIO DOME PART OF THE UP-DOMED SEA BOTTOM AND
NOT THE PALEOZOIC OLDLAND

At a subsequent period in the history of the region, the Ontario area was elevated into a low dome, one of the numerous domes formed at the end of Paleozoic time in eastern North America. During the Mesozoic era this dome was peneplained, with the result that all the covering strata were removed from the center of the dome, exposing the old crystallines, which during much of Paleozoic time formed a deeply buried sea floor. These crystallines are therefore a part of the up-domed sea bottom and not the oldland of Paleozoic time, and the Paleozoic strata on its flanks are merely the edges of beds which once extended entirely across them. On these rimming remnants of sea-bottom deposits the present cuesta and lowland topography was carved, much as the rimming series of hogbacks and concentric lowlands were carved on the edges of the strata exposed after the



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FIG. 13—Diagram illustrating the folded Appalachian strata in the coastal plain region and the basining and doming in the region away from the shore.

A=Appalachian folds and Oldland; P=Pennsylvania Basin; N=New York Basin; O=Ontario Dome. The Ordovician, Silurian (black), and Devonian formations are shown. The Carboniferous is indicated by dotted lines. The Appalachian folds probably did not appear as such on the surface.

FIG. 14—Generalized diagram illustrating the formation of the cuesta and lowland topography on the borders of the Ontario Dome.

O=Ordovician cuestas; N=Niagara (Silurian) Cuesta; D=Devonian cuestas; A=Alleghany Plateau.

erosion of the Black Hills dome, only that there the strata are more steeply inclined. The accompanying diagrams, Figures 13 and 14, illustrate these features.

RADIAL ARRANGEMENT OF DRAINAGE AS EVIDENCE OF UPLIFT
OF ONTARIO DOME IN TERTIARY TIME

A further fact must, however, be noted. There is evidence that this

Ontario Dome suffered a renewed though slight elevation in early Tertiary time, for the consequent rivers which initiated the new drainage system had a roughly radial arrangement. This is excellently shown in the arrangement of the Finger Lake valleys of New York, an arrangement frequently noted and commented upon. For it is now recognized that these valleys were originally formed by consequent streams flowing from the north, though nearly all of them have subsequently been deepened by glacial erosion. A glance at the map (Fig. 15) shows this radial arrangement at once, and further comment is unnecessary. There are, however, a number of buried valleys which are not so easily recognized in the present topography but which readily take their place in the radial series of these consequent streams, which flowed from the rejuvenated Ontario Dome. The broad valley now occupied by the Genesee River from Rochester south to Mt. Morris is one of these. This continues as a pronounced open valley southward to Dansville, beyond which it can be followed without difficulty, though somewhat obscured by drift, to the Susquehanna drainage system. This valley has been greatly deepened by glacial erosion as far as Dansville, but south of that it retains its preglacial character except for a moderate amount of drift filling. A second parallel valley, lying farther to the west,

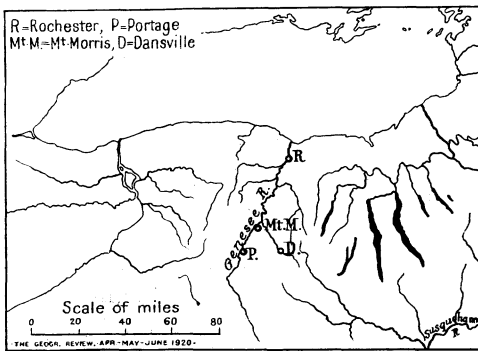


FIG. 15—Map showing (in solid black) the arrangement of the Finger Lake valleys in New York state.

is occupied by the modern Genesee from Portage southward, and the northward extension of this valley can likewise be traced with considerable accuracy. An even larger valley, which appears to have been cut by the main consequent stream from the Ontario Dome, is that of the ancient Dundas River (map, Fig. 16), which ran south-westward through the western end of Lake Ontario and was a member of the Mississippi drainage system. The valley of this stream is largely obscured by drift, but where it cuts the Niagara Cuesta, near Hamilton, Ontario, its width is nearly three miles. Finally, there is sufficient indication that a large river, flowing more nearly westward from the old Ontario Dome, cut the broad and deep notch through the Niagara Cuesta which now connects Georgian Bay and Lake Huron. This river was apparently responsible for the formation of the valley of Saginaw Bay, and it has been traced through borings at least as far as central Michigan.

We thus clearly perceive the radial arrangement of the Tertiary stream

valleys around a part of the old Ontario Dome, from the southeastern slope, where the valleys have a distinct southeasterly direction, to the western side, where the ancient valleys, now largely obscured by drift or submerged beneath the lake waters, have a marked westward trend. The tracing of other valleys farther east on the Ontario Dome is rendered difficult by the fact that here a second dome, the Adirondack, with its own drainage system, existed. Southwest of the Ontario Dome lies the Michigan Basin, and northwest of that the Wisconsin Dome. Thus in this region, too, the drainage was complicated by other drainage systems. The old drainage valleys on the north of the Ontario Dome have not been located, but when this region is more fully explored their existence will doubtless be shown.

The general character and direction of the Tertiary valleys on the known southern and western sides of the Ontario Dome are, however, quite sufficient to establish the fact that the Tertiary drainage system of this region was a radial one, and this can in my view be explained only on the basis of a renewed, though relatively slight, uplift of the Ontario Dome in Tertiary time. With the entrenchment of these radial consequents beneath the surface of the old peneplain, the possibility for the formation of rimming lowlands on the softer strata was developed, and in this process of lowland cutting the escarpment or cuesta infaces came into existence on the harder strata.

DEVELOPMENT OF THE DRAINAGE SYSTEM IN THE EASTERN GREAT LAKES REGION IN TERTIARY TIME

The most pronounced of the inner lowlands thus formed is the one now occupied by Lake Ontario. This valley was continued northwestward in the valley partly filled by the waters of Georgian Bay. The former connection between these two valleys is now filled by drift deposits, but a sufficient number of borings is known to prove such a connection. The valley of Georgian Bay was originally cut by streams tributary to the Saginaw River, and on the same soft Ordovician shales on which the Ontario Valley was carved by streams tributary to the Dundas River. The floor of the Georgian Bay Valley is, however, about two hundred feet lower than the lowest point in the now submerged floor of the gap which the Saginaw River cut through the Niagara Cuesta, and this indicates that at a later stage in the development of these river systems the headwaters of the Saginaw were captured by a branch of a more powerful stream working on the soft strata. This master stream was the Dundas River, the northwestern tributary of which, working along the base of the Niagara Cuesta in Canada, finally diverted the upper portion of the Saginaw drainage system into that of the Dundas. An eastern arm of this same master stream successively captured the headwaters of the southward- and southeastward-draining consequent from the Ontario Dome and thereafter deepened its valley to such an extent on the soft shales that the floor of this subsequent valley now lies in places nearly

a thousand feet lower than that of the beheaded consequents whose valleys we now trace in the Finger Lakes and in the several valleys of the Genesee country. Thus was developed the deep and broad valley of Lake Ontario, the rivers of which became tributary to the ancient Dundas drainage system, while the beheaded stream valleys of the other consequents—the Finger

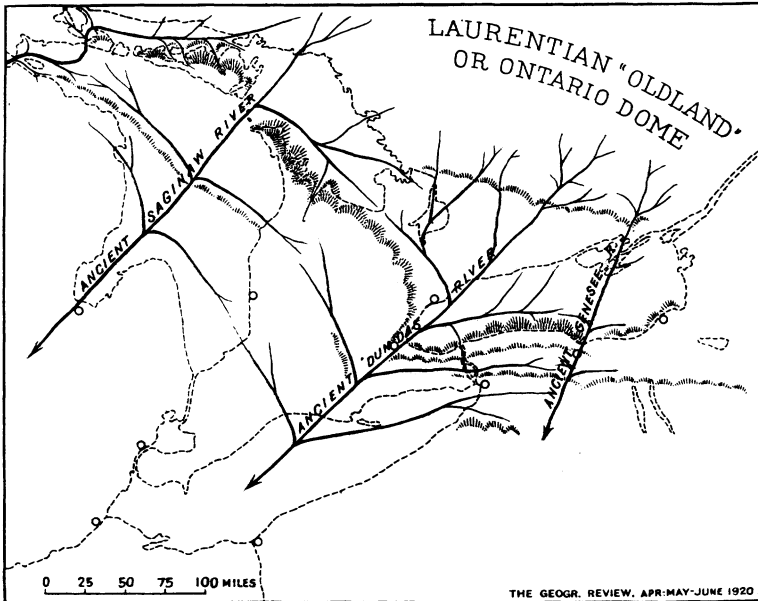


FIG. 16—Generalized map showing restoration of the drainage systems existing in early Tertiary time in the Ontario Dome region with their radial arrangement. (After Fig. 5, "Guide to the Geology and Paleontology of Niagara Falls and Vicinity," by A. W. Grabau, *New York State Museum Bull. No. 45*, Albany, 1901.)

Lake series—now end in the air at the edge of the Niagara Escarpment. In the accompanying two maps (Figs. 16 and 17) these steps in the development of the drainage system are shown.

FINAL STAGE IN THE DEVELOPMENT OF THE MODERN DRAINAGE SYSTEM

The final stage in the development of the modern drainage system was inaugurated by the overdeepening of most of the north-south valleys by the ice during the succeeding glacial periods and was completed by the deposition of heavy moraines within these old valleys, for the most part to the south of the overdeepened portion. The ancient outlet of the Ontario drainage system, the Dundas Valley, was completely blocked by drift, as were also portions of the Ontario-Georgian Bay lowland in the region flanking the Dundas Valley. Finally, the fact, apparent on the disappearance of the ice, that the entire region surrounding the Ontario as well as the Adirondack Dome had been depressed to a considerable amount during the occu-

pancy of this region by the ice induced a reversal in direction of the streams which reoccupied the old valleys, and thus the entirely abnormal St. Law-

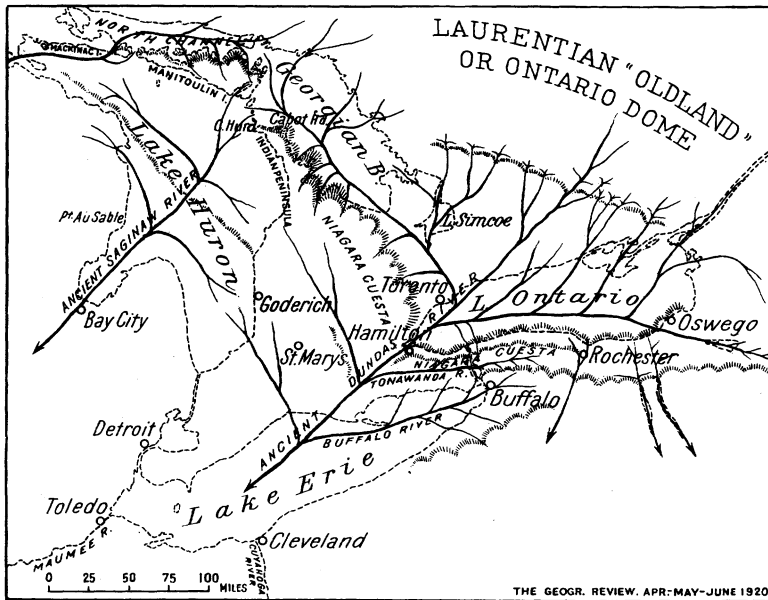


FIG. 17.—Generalized map showing a probable later stage of the Tertiary rivers of the Ontario Dome with their capture and adjustment to the strata as suggested by the existing relief features. (After Fig. 6, *New York State Museum Bull. No. 45.*)

rence drainage system came into existence. If the Ontario and Adirondack Domes region were raised a thousand feet or more and if the obstructing drift were removed from the old valleys, the original southward drainage would become re-established. Along the lines of many of these ancient consequent streams, however, lakes would be formed, these occupying the over-deepened portions of the valleys, such as those of the Finger Lake valleys of New York. The St. Lawrence would again head in the Thousand Islands region, where would also originate a southwestward-flowing stream, tributary to the Ontario and Dundas Rivers. The Mohawk divide at Little Falls would become re-established, the western stream from this divide joining the Ontario River, while the eastern stream would continue to the Hudson as does the Mohawk today. This shortened Mohawk and the revived stream from the Lake Champlain region would re-establish the subsequent drainage system which was formed around the southern and eastern margins of the Adirondack Dome in Tertiary time. In relation to this system the Hudson has at least a partial consequent habit.